Temporal trends and seasonal and multi-year variability of ozone, water vapor and temperature throughout the stratosphere

Karen Rosenlof (with Birgit Hassler and Sean Davis)
NOAA Earth System Research Laboratory
Chemical Sciences Division
303 497-7761, Karen.H.Rosenlof@noaa.gov

CDR Team Meeting
July 31 – Aug 2, 2012

- Project Description: Combine measurements of ozone and water vapor from recent satellite missions. Time period will extend from the mid 1980s to the present.
- Applications: Analysis of trends and variability, assessment of CCM simulations; ozone boundary conditions for global climate model simulations without interactive stratospheric chemistry; stratospheric water vapor boundary conditions for model sensitivity studies; inferences on trends and variability in stratospheric transport.
- Users: IPCC, Ozone Assessment (IOC) & SPARC/IGAC AC&C communities

Project Description

- We have 4 types of data sets for stratospheric ozone, and 2 for stratospheric water vapor.
- Ozone: there is an individual ozone profile compilation (this is referred to the BDBP), two monthly average versions (one involving computing shifts between satellites), and a regression fit.
- Water: there is a monthly average version with adjustments between satellites and one without.
- For model studies, filled versions (either via regression models or interpolation of anomalies) have been generated.

Why are we interested in stratospheric H_2O?

1) It impacts radiative processes including stratospheric temperature (potentially even impacting surface temperatures)

2) It impacts ozone chemistry in the stratosphere (via influence on OH chemistry, but also changing polar stratospheric cloud occurrence.)

3) From measurements of the mean distribution and variations we can infer something about temperatures and stratospheric motions.

4) Source to the mesosphere. Trends in stratospheric water + methane may ultimately result in trends in the mesosphere (and the interest here is potential trends in PMCs).

Why are we interested in stratospheric O_3?

1) Monitoring for ozone recovery.

2) It impacts radiative processes including stratospheric temperature (potentially even impacting surface temperatures and circulation)

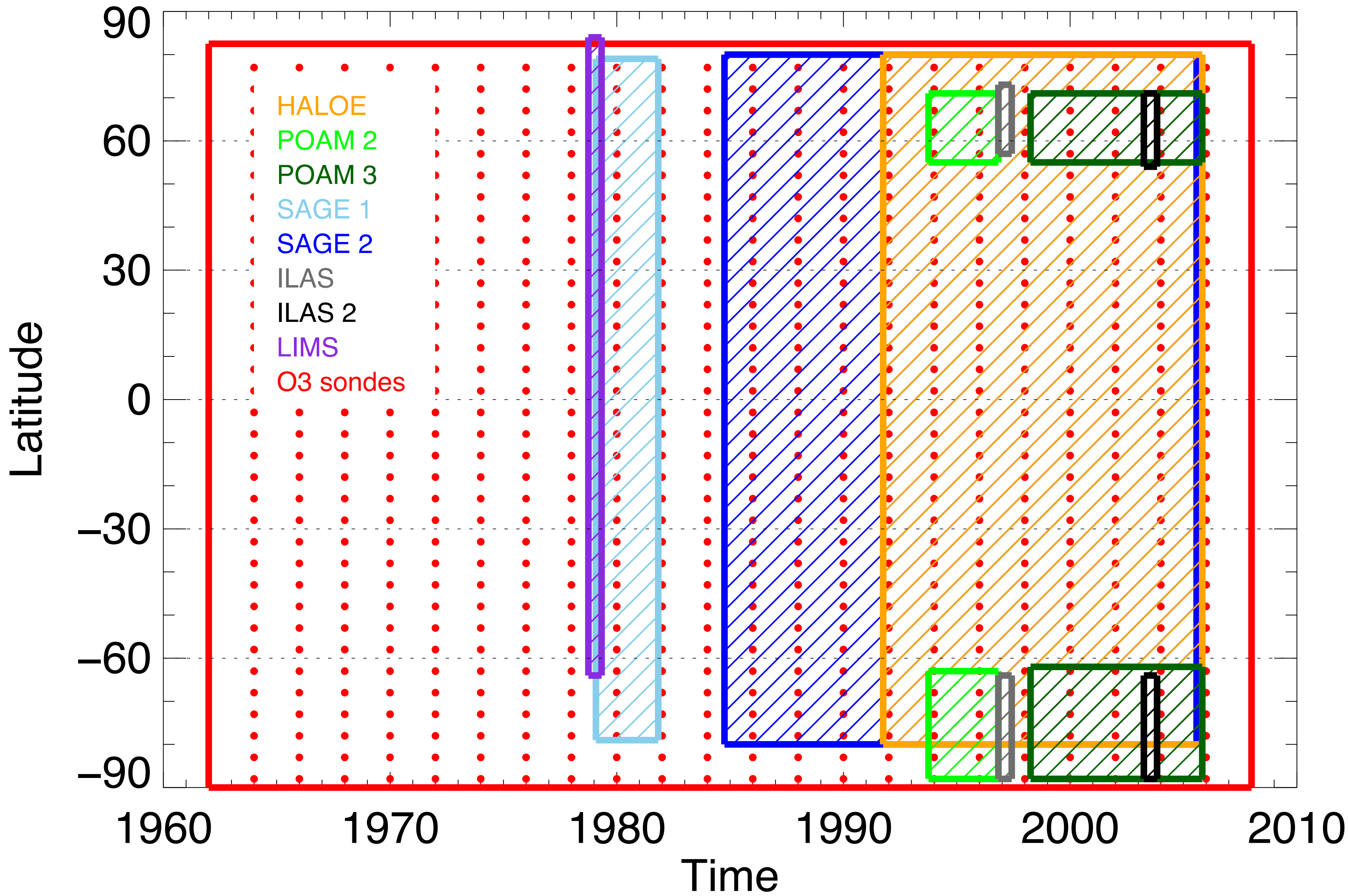
3) From measurements of the mean distribution and variations we can infer something about temperatures and stratospheric motions.

Water vapor compilation will be considered in the into the SPARC water vapor activity.

Ozone work will be considered in the The SI²N Initiative on Past Changes in the Vertical Distribution of Ozone (SPARC, IOC, IGAC and NDACC)

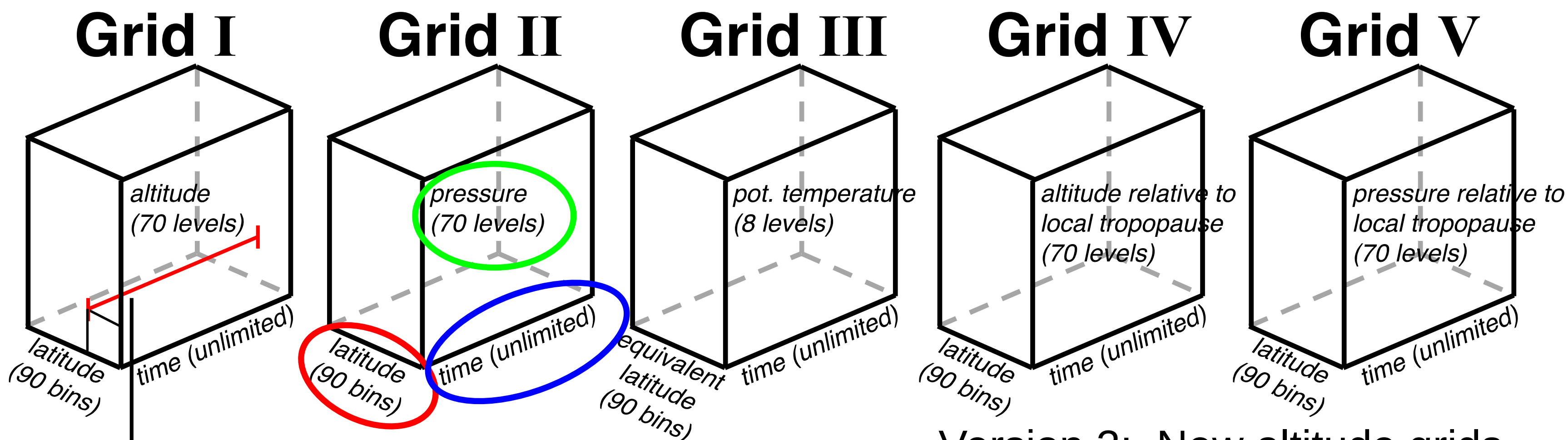
Ozone Database (#1)

- BDBP – "*Binary Database of Profiles*" (done with Greg Bodeker currently at Bodecker Scientific in New Zealand)
- Several different satellite-instruments and ozonesondes
- High resolution vertical profiles (so far mainly measurements by occultation instruments - solar or stellar - and sondes)
- Individual measurements saved on pre-defined database levels for pressure (70 levels), altitude (70 levels) and potential temperature (8 levels)
- Each profile is stored in each of the different database grids
- Ancillary data includes equivalent latitude
- Includes NO_2, H_2O, NO, CH_4, HCl, HF and aerosol extinction.
- QC'd and percentage uncertainty estimates included



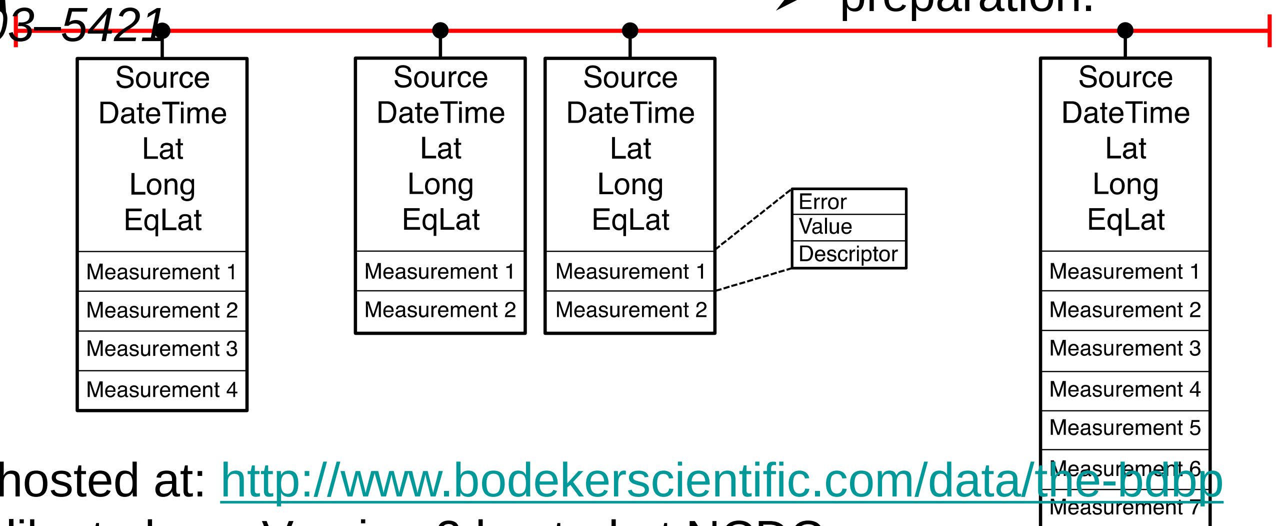
90
60
30
0
–30
–60
–90
Latitude
1960
1970
1980
1990
2000
2010
Time
HALOE
POAM 2
POAM 3
SAGE 1
SAGE 2
ILAS
ILAS 2
LIMS
O3 sondes

Database structure



Version 1: Hassler, B., G.E. Bodeker, and M. Dameris (2008). Atmos. Chem. Phys., 8(17), 5403–5421

Version 2: New altitude grids and some new data sources, in preparation.



Version 1 hosted at: http://www.bodekerscientific.com/data/the-bdbp

We would like to have Version 2 hosted at NCDC

Ozone Database (#2)

- Vertically resolved and latitude/monthly gridded data set
- Based on the BDBP
- Used for subsequent representations of the data

Ozone Database (#3)

- Gap free latitude/time gridded version of the monthly averaged BDBP
- Multiple fitted versions provided using progressively more complex basis functions, solar,trends,qbo,annual, volcanic

Publication recently submitted to Earth System Science Data
Bodeker, Hassler, Young and Portmann, A vertically resolved, global, gap-free ozone database for assessing or constraining global climate model simulations. Currently available via ftp from Bodeker Scientific…we want to make it available at NCDC

Ozone Database (#4)

- Based on SAGE II&III, HALOE, UARS and Aura MLS
- Monthly averaged and latitudinally binned
- Comparisons are made with matching raw profiles to estimate adjustments in mixing ratio space
- Adjustments are a function of latitude and altitude
- Binning is done both in geographic and equivalent latitude space.
- A filled version is available, with interpolations in anomaly space.
- We intend to use the sonde measurements for independent verification of this filled data base.

Water Database (#1)

- This is constructed in the same manner as the ozone database (#4)

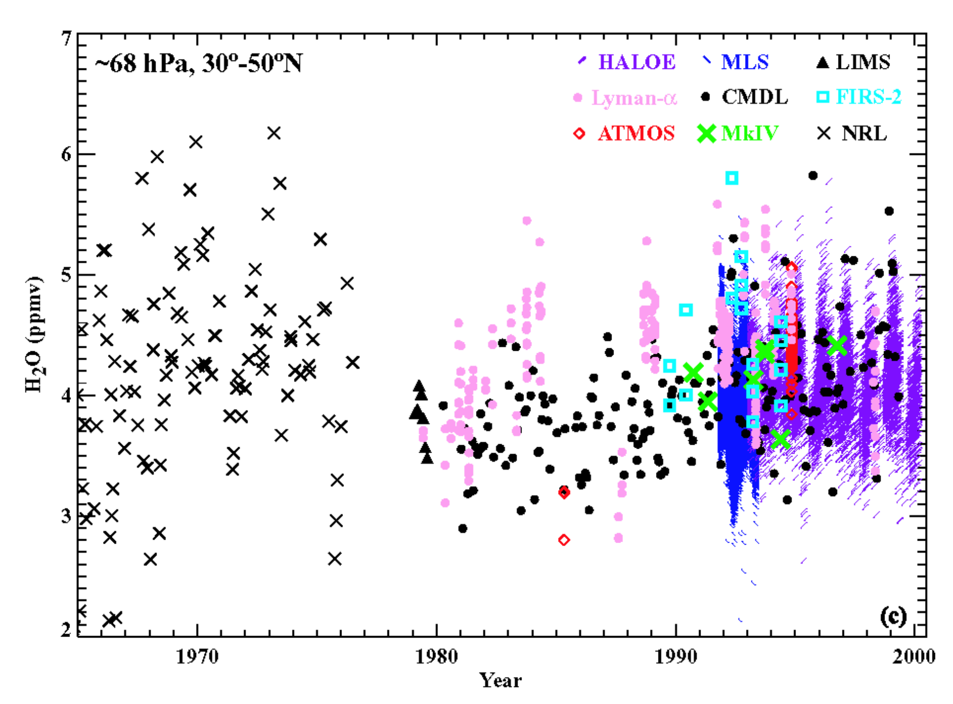
- Is currently available in beta version via ftp at NOAA ESRL CSD.

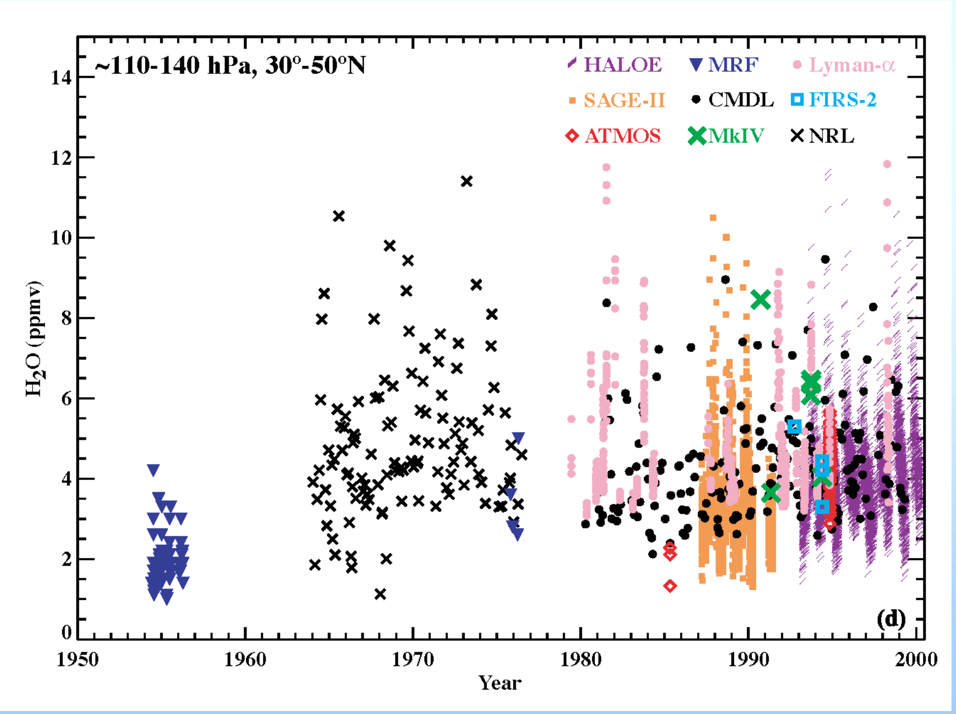
SWOOSH (Stratospheric Water and OzOne Satellite Homogenized), constructed by Sean Davis (CU/CIRES and NOAA/ESRL).

Manuscript currently in preparation: Davis and Rosenlof, will be submitted to ACPD for the SI^2N Initiative special issue being organized by Neil Harris.

Problem: Stratospheric water vapor observations are not consistent in time

Stratospheric water vapor measurements have not been taken continuously at any one location or with any one technique for an extended period of time.

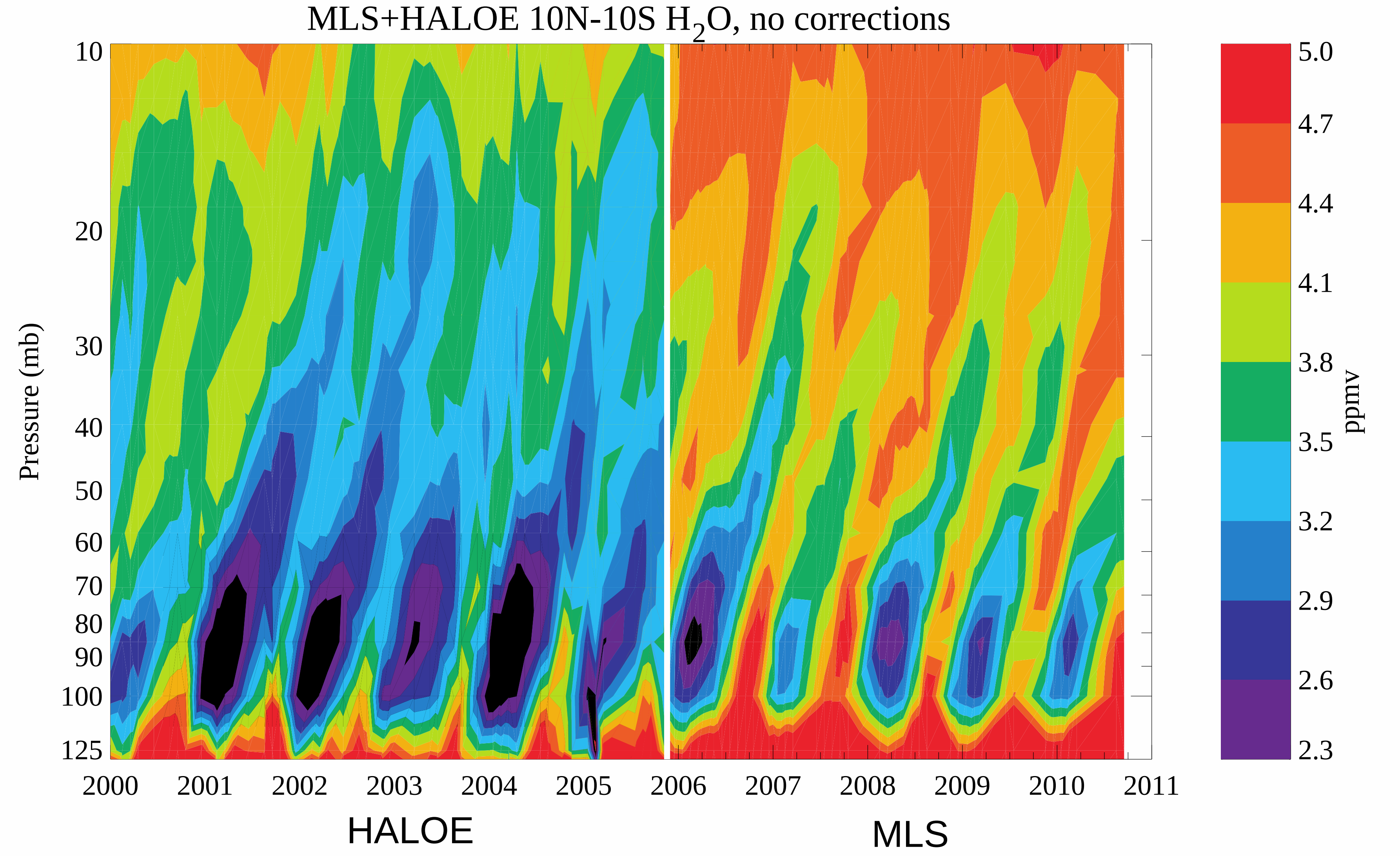




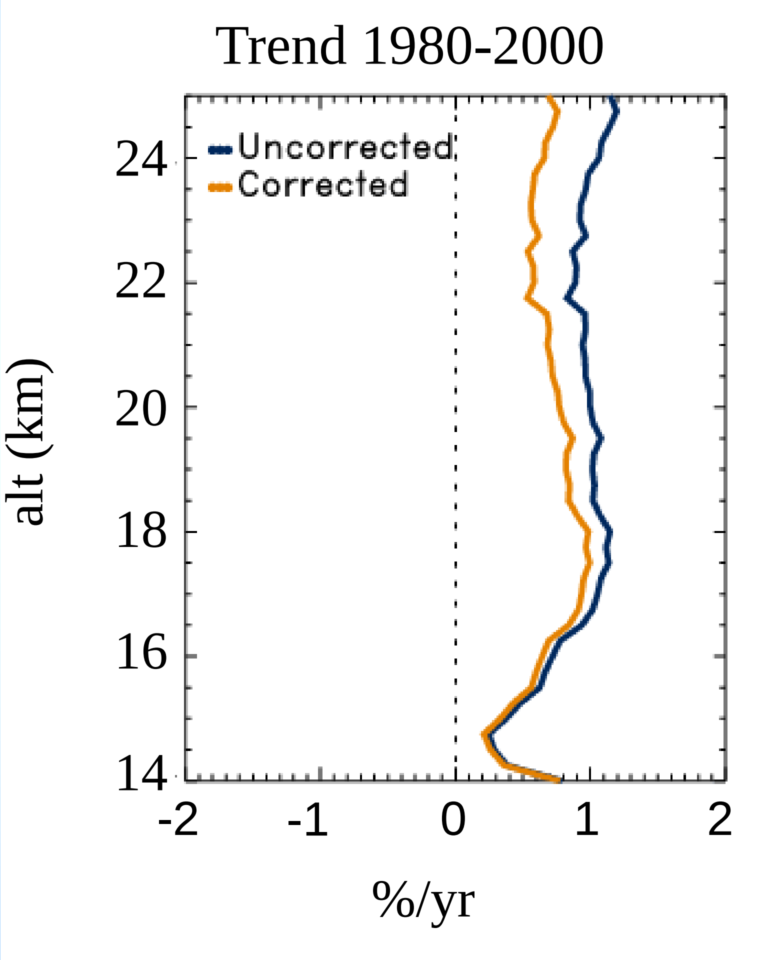
Ideally, we would like to be able to combine data sets to get an extended record, but first we need to assess whether different measurement systems are retrieving the same values at the same time/location.

Demonstration of stratospheric satellite measurement offsets

Tropical tape recorder plot: This shows the temporal evolution of tropical stratospheric water vapor over the past decade.



What sort of trends exist for stratospheric water vapor?



Note: trends are 0.5-1%/year, instruments differences are 5-10% or larger, so a simple combination will produce spurious trends.

Note: a trend of 10%/decade is equivalent to a 0.5 ppmv change

From Scherer et al, ACP 2008

Methodology for SWOOSH

1) Choose data sets with long continuous records, preferably global coverage, and some overlap in time/space.

2) Determine which data set to which to adjust.

3) Analyze the overlap period to determine adjustments that need to be made before combining data sets.

4) Establish the uncertainties for each part of the combined time series.

5) Determine some means of filling missing data (for cases where a complete data set is needed for model input.

Approach

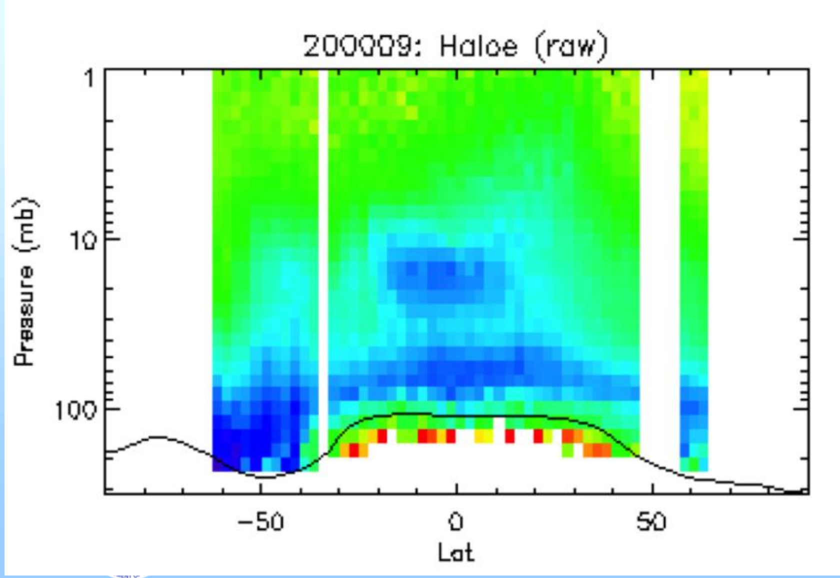
Data sets to consider:

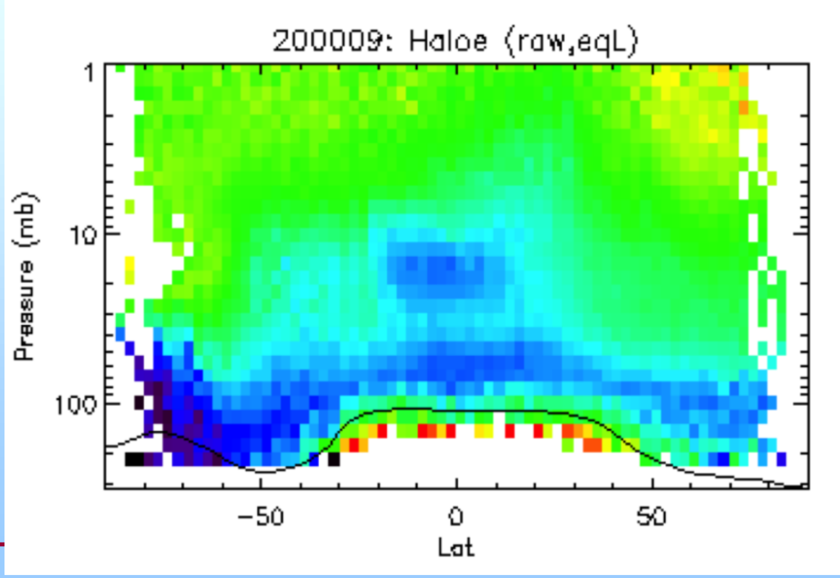
1) SAGE II: 1985-2005
2) HALOE: 1991-2005
3) Aura MLS: 2004-present

To fill in gaps in polar regions; ACE (2004-present) can be used. Additionally, there are other shorter period satellite records.

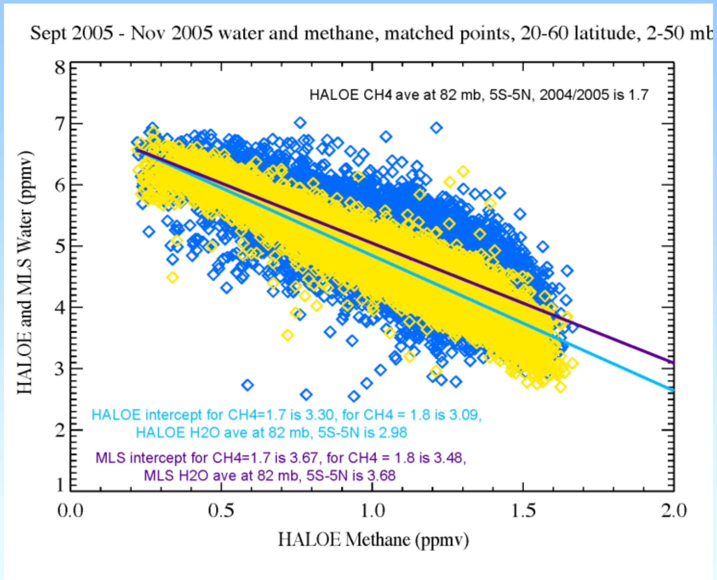
Zonal average time series gridded with respect to equivalent latitude

Use of equivalent latitude allows greater latitudinal coverage.





How did we pick a basis instrument? (data shifted to match Aura MLS)



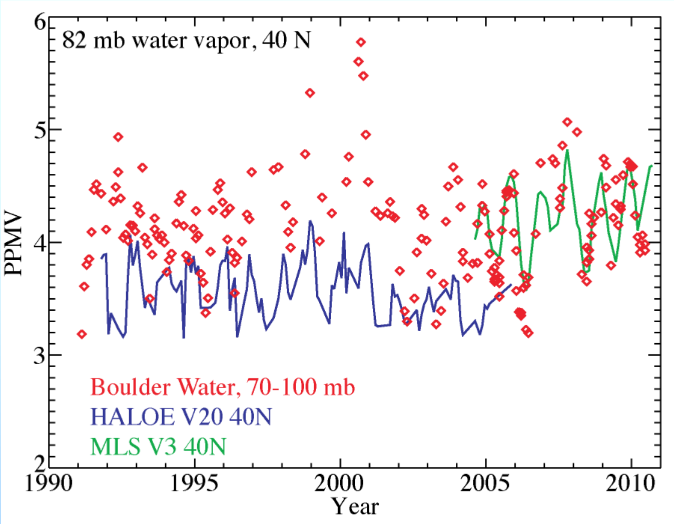
Use 2 methods to calculate entry value H_2O:

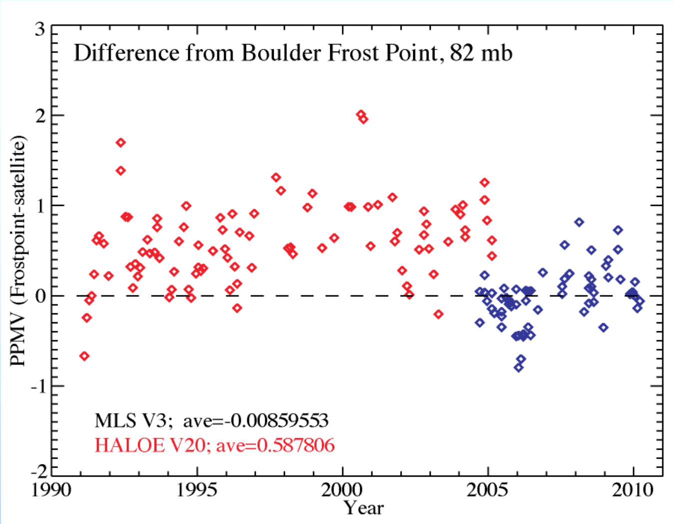
1) intercept for the water/methane relation at mid latitudes in the middle stratosphere
2) water value just above the tropical tropopause

GMD CH_4 surface value in 2007 was ~1.775 ppmv

HALOE gives 3.1-3.3 for method 1; ~3 for method 2
MLS gives 3.5-3.7 for method 1; ~3.7 for method 2

MLS seems more consistent with the two methods of calculation.





MLS differences from Boulder frost point are smaller (by ~.5 ppmv) than HALOE differences. We have therefore decided to compute the adjustment to MLS for the overlap period (2004 & 2005), and use those adjustments for the entire HALOE data set. This makes the assumption that there has been no drift in the HALOE measurements over the 1992-2005 time frame.

Database construction

Equivalent latitude, θ from MERRA

SAGE-II (v6.2) | UARS HALOE (v19) | UARS MLS (v6) | Aura MLS (v3)

Quality control of profile data

- Filter out bad data (all instruments)
  - Aerosol or cloud contamination, poor retrieval uncertainty
- Remove extreme outliers (SAGE only)
  - O_3 > 15 ppmv, or H_2O > 25 ppmv (and $p \leq 100$ hPa)
- Remove outliers using 3σ filter (SAGE only)
- MLS UTLS H_2O adjustment
- Grid all data onto Aura MLS pressure grid

Match profiles with Aura MLS

- Match criteria: $\Delta x \leq 1000$ km, $\Delta t \leq 24$ hours, $\Delta eqlat \leq 7.0°$
- Minimum equivalent latitude is used if multiple profiles

Calculate offsets relative to Aura MLS

- Defined as the mean of (Aura MLS – "Other")
- Calculated in 10° lat bins, at each pressure level

Grid data

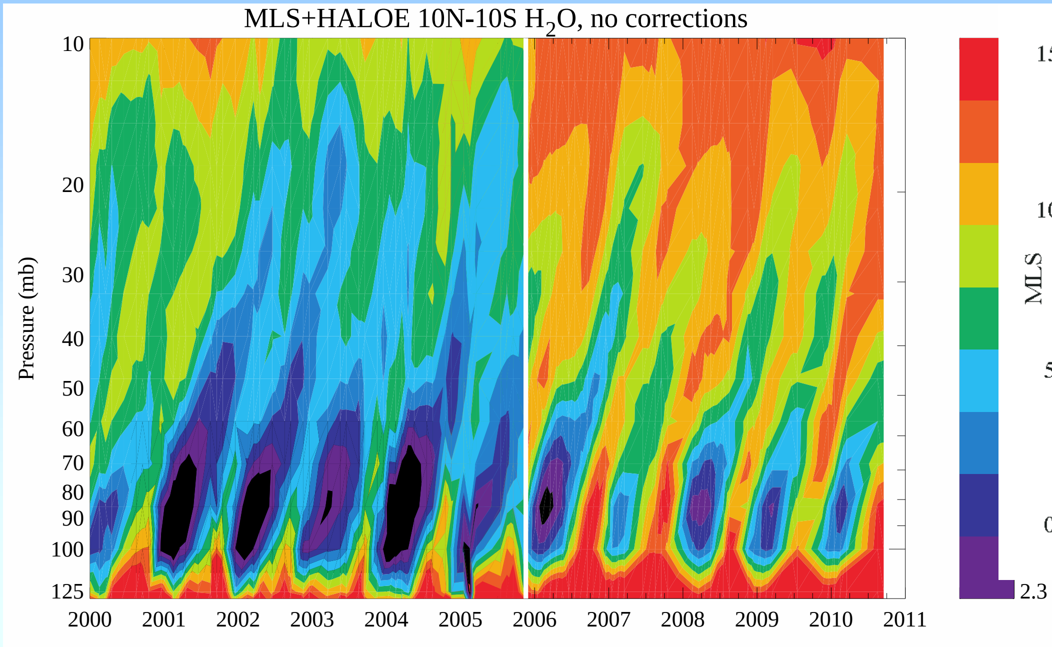
Resolution:

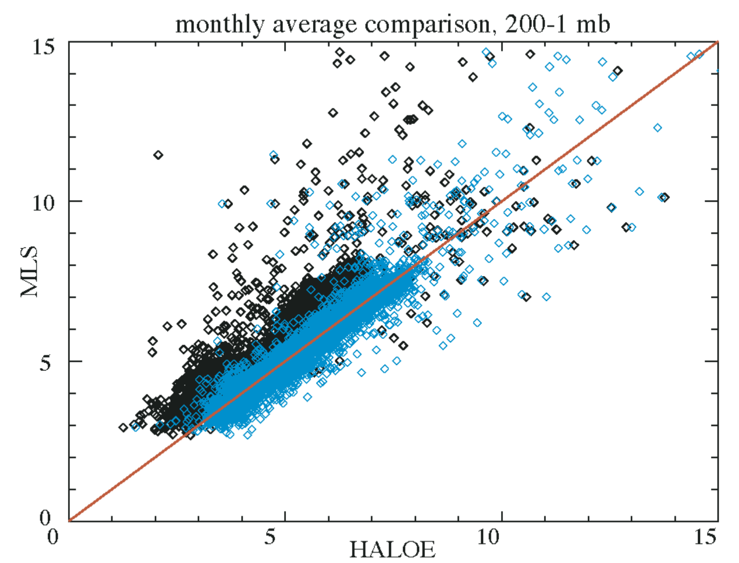
- Monthly-mean (1984 – present)
- Zonal-mean (both 2.5° and 10° lat)
- 40 pressure levels (316 - 0.01 hPa) and 21 isentropic levels (300-650 K)
- Geographic and equivalent latitude grids for each variable

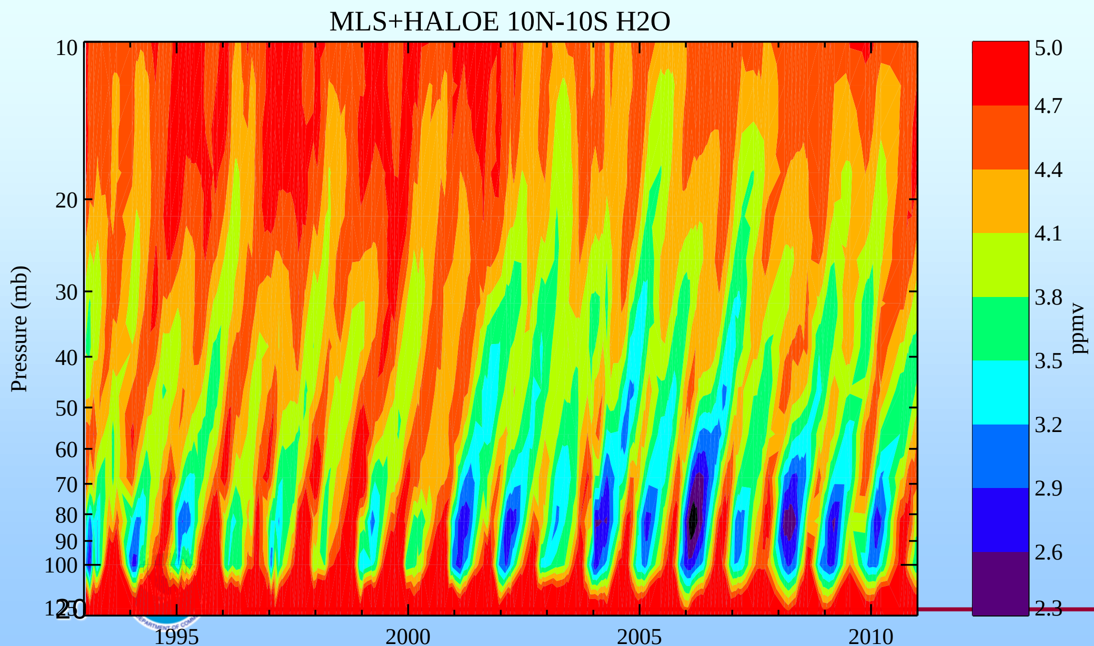
Information stored (lat, level, time):

- Mean, standard deviation, mean uncertainty, # of profiles in bin
  - For each satellite
  - Both uncorrected and corrected versions
- Combined -- weighted mean of all available measurements
- Combined, with anomaly-filling procedure

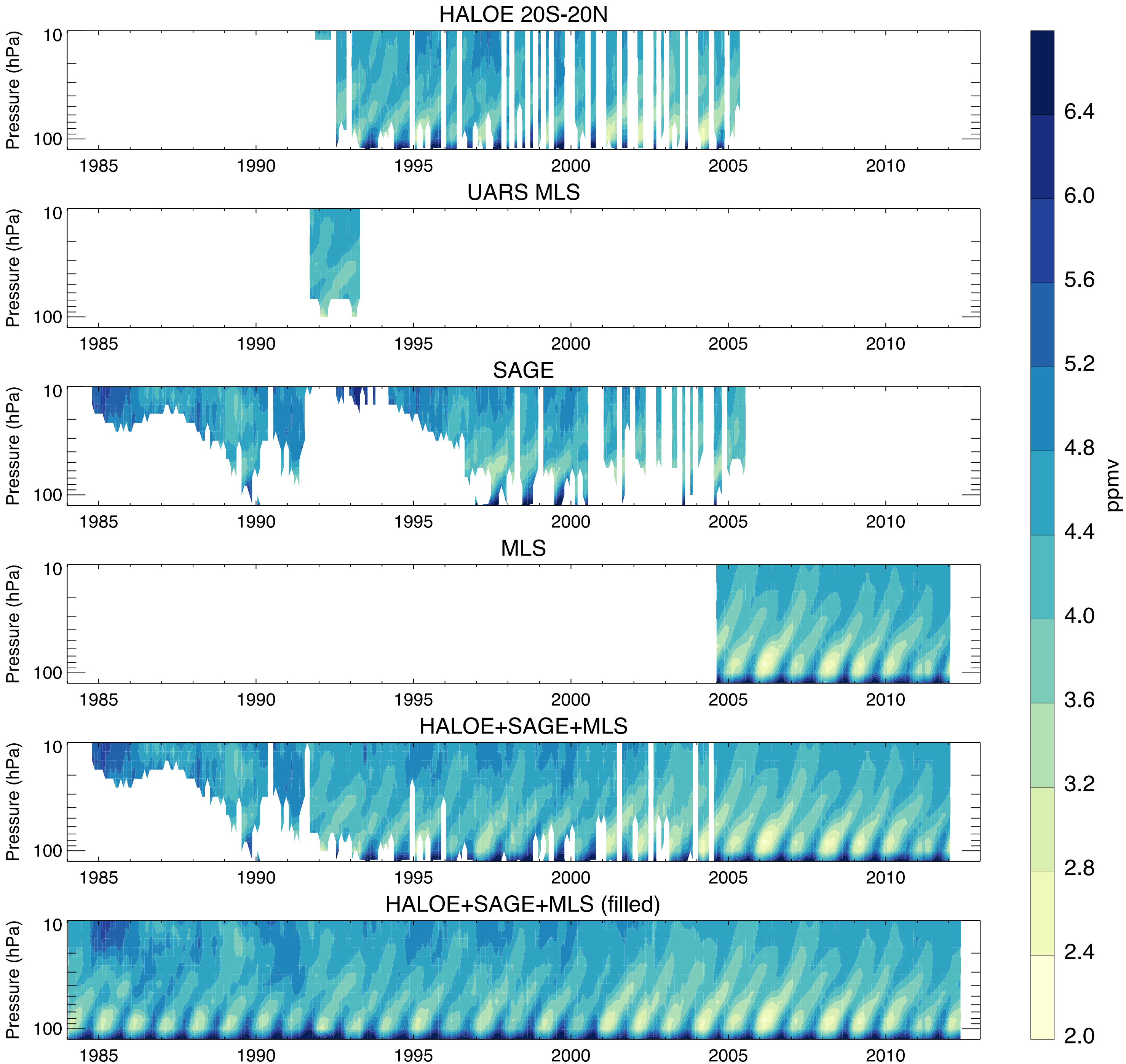
Example of impact of adjustment



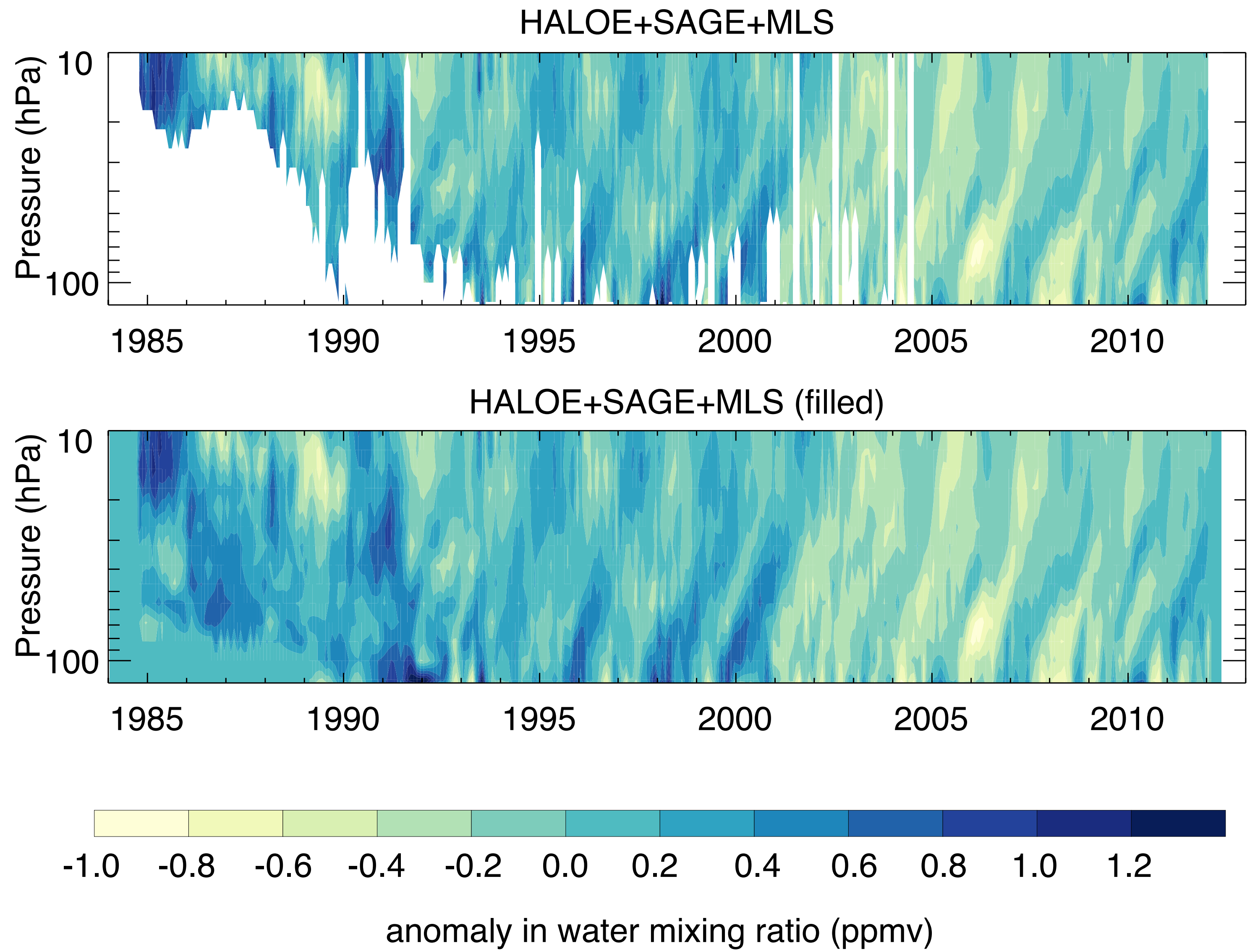




Correlation without correction: 0.79
Correlation with correction: 0.91



HALOE 20S-20N
UARS MLS
SAGE
MLS
HALOE+SAGE+MLS
HALOE+SAGE+MLS (filled)
Pressure (hPa)
10
100
1985
1990
1995
2000
2005
2010
ppmv
6.4
6.0
5.6
5.2
4.8
4.4
4.0
3.6
3.2
2.8
2.4
2.0


HALOE+SAGE+MLS
Pressure (hPa)
10
100
1985
1990
1995
2000
2005
2010
HALOE+SAGE+MLS (filled)
Pressure (hPa)
10
100
1985
1990
1995
2000
2005
2010
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
anomaly in water mixing ratio (ppmv)

Schedule & Issues

- Project Status: Our proposal has three objectives
  - 1) satellite record comparison during overlap periods: **done** for MLS/SAGE/HALOE water and ozone, **in progress** for other satellites (ie ACE, possibly MIPAS and balloons)
  - 2) use the water vapor and ozone time series to do trend and cycle analysis. In particular, we will examine features related to the change in tropical water vapor, temperatures and possible circulation changes that occurred at the end of 2000. **In progress**…a paper detailing anomalous NH polar ozone and relation to the tropics over the winter of 2010/2011
  - 3) analyze large-scale transport changes and radiative and climate impacts of observed changes and variability in stratospheric water vapor and ozone. **Done** for radiative forcing and ozone, **in progress** for radiative forcing and water vapor, **partially done** for transport changes.

- State any risks or concerns
  - We expect to complete the majority of what we set out to do by the end of FY13.

- How can the CDR Program better assist you?
  - When complete, we would like the data sets hosted by NCDC to increase use.

Publications about or using the BDBP or SWOOSH

Evan et al, (to be submitted to JGR) The representation of the TTL in a tropical channel version of the WRF model.

Hassler et al., 2012 (just submitted to ACP) Comparison of three vertically resolved ozone data bases: climatology, trend and their radiative forcing

Hassler et al., 2011, An assessment of changing ozone loss rates at South Pole: Twenty-five years of ozonesonde measurements, JGR, DOI: 10.1029/2011JD016353

Hassler et al, 2011, Changes in the polar vortex: Effects on Antarctic total ozone observations at various stations, GRL, DOI: 10.1029/2010GL045542

Karpechko et al, 2010, Quantitative assessment of Southern Hemisphere ozone in chemistry-climate model simulations, ACP, 10, Issue 3, pp 1385-1400. (Also uses first version of SWOOSH)

Hassler et al, 2009, A vertically resolved, monthly mean, ozone database from 1979 to 2100 for constraining global climate model simulations, International Journal of Remote Sensing Volume: DOI: 10.1080/01431160902821874

Hassler et al, 2008, Technical Note: A new global database of trace gases and aerosols from multiple sources of high vertical resolution measurements, ACP, 8, Issue 17, pp 5403-5421.

Publications about or using SWOOSH:

Rosenlof and Reid, 2008: Trends in the temperature and water-vapor content of the tropical lower stratosphere: The sea-surface connection, *J. Geophys. Res.* doi:10.1029/2007JD009109.

Dall'Amico et al., 2010: Impact of stratospheric variability on tropospheric climate change, *Climate Dynamics*, doi:10.1007/s00382-009-0580-1.

Dall'Amico et al, 2010: Stratospheric temperature trends: impact of ozone variability and the QBO, *Climate Dynamics*, doi:10.1007/s00382-009-0604-x.

Ray et al., 2010: Evidence for Changes in Stratospheric Transport and Mixing Over the Past Three Decades Based on Multiple Datasets and Tropical Leaky Pipe Analysis, *J. Geophys. Res*., doi:10.1029/2010JD014206.

Solomon et al., 2010: Contributions of Stratospheric Water Vapor Changes to Decadal Variations in the Rate of Global Warming,*Science,* **327***,* 1219-1223*.*

Davis and Rosenlof*, (to be submitted to ACPD)* Satellite based zonally averaged time series of stratospheric water vapor